MICROWAVES

Part VII—Action of below-cutoff attenuators, and of TR and anti-TR switches

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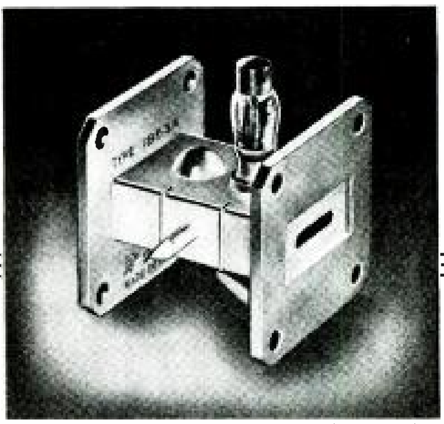


Courtesy Sylvania Electric Products Inc.
A TR assembly for waveguide insertion

WE discussed waveguide attenuators in a general way in an earlier part of this series and showed how a resistance strip could be inserted into a waveguide to introduce an adjustable amount of attenuation.

Another type of attenuator used extensively in microwave work is called the "waveguide-below-cutoff" attenuator or sometimes simply the *cutoff* attenuator.

A wave propagates through a waveguide with very little loss, provided the diameter or width of the guide is greater than the cutoff point. If these dimensions are below cutoff, then there is no longer any real wave propagation; instead the magnetic and static fields of the r.f. waves are attenuated very rapidly down the length of the guide.

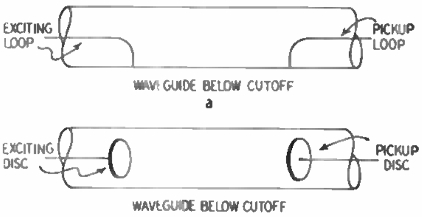


Fig. 1—Couplings are loops or discs.

If the guide diameter is made small compared to the free-space wavelength, the attenuation is independent of frequency over a very wide range. The modes generally used for such attenuators are the $TE_{1,1}$ and the $TM_{0,1}$. The methods of exciting waveguides in these two modes are shown in Fig. 1. Here a co-axial line is terminated in either a coupling loop or disc and the reduced power is picked up in another co-axial line. The distance between the exciting and pickup loops controls the amount of attenuation. Since the relationship is linear, a scale on the movable loop or disc can be calibrated directly in decibels. Attenuators of this type usually have an insertion loss of about 10 to 20 db at the position of maximum coupling and more as the coupling is reduced.

When co-axial line is coupled into a cutoff attenuator with loops, a serious mismatch to the line results, a co-axial line terminating in a loop being practically short-circuited. Three methods of reducing the bad effects of such mismatch may be used. The most common is to pad the input and output ends of the cutoff attenuator with lengths of high-loss co-axial cable. These add about 10 db of attenuation, and their resistance damps out the effects of reflection from the mismatched co-axial line termination.

Another way is to use resistor discs, little circles of graphite or carbon, made to fit the co-axial cable, with a hole in the center to contact the inner wire. The resistance of these discs should be equal to the characteristic impedance of the line so that the line is terminated correctly.

A third method is to make the loops of a resistance material and adjust the resistance of the loop to equal the characteristic impedance of the line.

Cutoff attenuators are also made to work in waveguide at the higher frequencies where co-axial line is not desirable because of high losses. Fig. 2 shows how this is done. A rectangular or circular guide is joined to the small "below-cutoff" section with a pickup probe near the termination of the large guide. This probe ends in a fixed loop for exciting the small guide. A second (movable) loop used as the pickup point ends in a probe extending into another section of large guide to continue the waveguide circuit.

The space between exciting and pickup loops is adjusted by one of several mechanical methods, the simplest of which consists of two telescoping metal tubes, each of which contains a loop and is terminated in the co-axial lines or waveguides. A rack-and-gear drive controls the amount of telescoping and, consequently, the spacing between loops, which varies the attenuation.

TR and ATR units

In radar and microwave communication systems in which the same antenna is used for both transmitting and receiving, it is necessary to use a fast-operating transmit-receive switch to prevent transmitter power from reaching the sensitive crystals and vacuum tubes of the receiver and also to prevent the received signal from being absorbed in the transmitter.

A transmit-receive (TR) box is an electronic switch which operates in a fraction of a microsecond. It must provide an excellent short-circuit for the receiver, since even a small part of the transmitter power would burn out a silicon or germanium crystal.

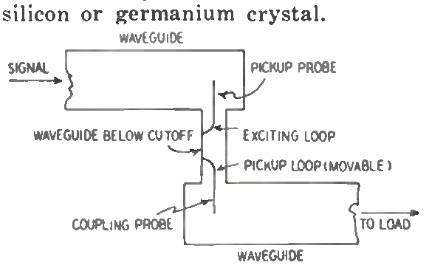


Fig. 2—Attenuator between waveguides.

Some form of gas discharge device is generally used for this purpose. Note Fig. 3. Here the transmitter power builds up a voltage across the gap, which then arcs over so that most of the transmitter power goes out to the antenna. This simple scheme could be employed in either a co-axial line or a waveguide, but unfortunately it doesn't offer enough protection to the receiver.

The simplest way to improve it is to insert a voltage step-up transformer before the gap and a step-down transformer after it. And this is just what is done, in the form of a *resonant cavity* in which the gap is placed.

This resonant cavity may take the form of a cylindrical box with perfectly conducting walls and with two posts in the axis of the cylinder, separated by a gap, as shown in Fig. 4. In the lowest mode that will function in such a cylinder, the electrical field is parallel to the axis of the cylinder and increases toward the center. The magnetic field

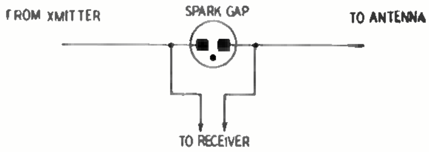


Fig. 3—The principle of the TR switch.

lines are circles perpendicular to the axis of the cylinder and currents tend to flow radially and up and down the center posts, as shown in the cross-section drawing.

Energy may be fed into and out of such a cavity either through windows in the cylinder walls or by coupling loops inserted into the cavity. The step-up ratio of the transformer is controlled by the size of the coupling windows or loops, the ratio increasing as the window or loop size is decreased.

When weak microwave currents pass through the waveguide or co-axial cable, the TR tube permits power to pass through. But if a strong wave—such as would be set up by applying power to the magnetron transmitter of Fig. 5—passes down the guide, the tube breaks down and becomes a short circuit. The shorting of the TR gap applies a "solid wall" at the junction of the T side arm of the waveguide, and sets up a strong standing wave in the side arm which prevents the transmitted signal from reaching the receiver.

In receiving, the magnetron is not fired, and since most magnetrons have a considerable change in impedance between hot and cold conditions, it is possible to tune the waveguide to provide a matched impedance condition when the magnetron is fired, thus introducing a gross mismatch when the magnetron is not fired. This sets up a standing wave in the line between the TR tube and the magnetron so that most of the received power goes through the cold TR box to the receiver.

Some magnetrons, particularly those on 3 cm and shorter wavelengths, do not change impedance enough to prevent an excessive loss of received signal. In these instances, an *anti-TR box* is used.

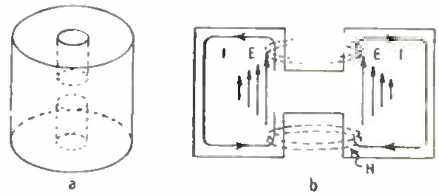


Fig. 4—Voltage is highest across gap.

The anti-TR box is very similar to the TR box except that it has only one coupling window instead of two. It is placed in a T side arm between the TR and the magnetron. On transmit, it fires just as the TR box does and reflects a solid wall at the junction of the T side arm, thus allowing maximum power to reach the antenna.

On receive, however, being situated a quarter-wavelength from the TR box and tuned in length so that when it is not fired it reflects signals coming from the direction of the antenna, it thus prevents loss of signal in the magnetron. If the distance from the anti-TR to the TR is correctly chosen, a maximum received signal will pass through the unfired TR to the receiver.

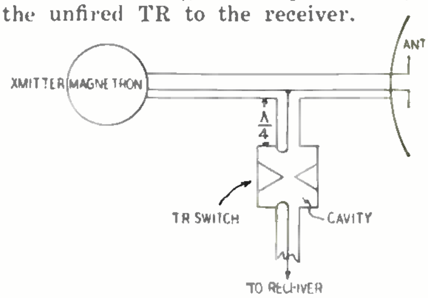


Fig. 5—TR switch in antenna circuit.

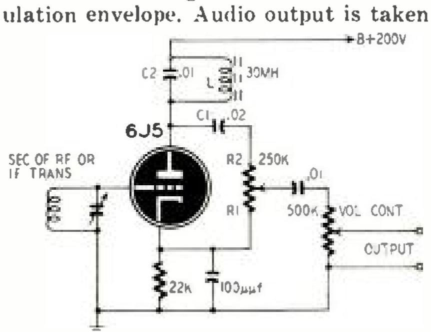
A TR switch may not fire in the first few cycles of the transmit signal and the high-voltage pulse may damage the receiver. To prevent this a "keep-alive" electrode is often built into the TR tube. An auxiliary electrode or gap near the main gap of the TR tube, it is connected to a source of voltage sufficient to keep a small arc always fired in the TR to supply the necessary ions to cause the main gap to fire on the first pulse from the transmitter. This causes a small loss of received signal, but prevents damage to the delicate receiver parts and is thus a worth-while compromise.

The use of TR and anti-TR switches in a microwave communication system permits duplex operation. Transmitter power can be applied momentarily to the antenna when it is desired to talk, but reception is possible at all times that the transmitter is not active. It also permits a single antenna and reflector system to be used for transmit and receive. This reduces cost and allows focusing on point-to-point transmissions to be simplified greatly. An even more important advantage is in radar, where the rotating antenna makes it extremely convenient to use one antenna for transmission and reception.

A DETECTOR-FILTER CIRCUIT

Heterodynes, caused by beating between adjacent-channel signals, are often annoying to users of high-fidelity receivers and tuners. A heterodyne filter is combined with an infinite-impedance detector in a circuit described in *Electronic Engineering* (London).

A parallel-resonant circuit L-C2 is inserted in series with the detector plate and B-plus in the circuit shown. The cathode bypass capacitor being small, the cathode voltage will follow the modulation envelope. Audio output is taken



from a bridge composed of the internal resistance of the tube, C1, R1, and R2. At frequencies above and below the resonant frequency of L-C2, the plate-circuit impedance is low and most of the audio voltage is developed in the cathode circuit. If R1 and R2 are equal and the reactance of C1 is low, the output voltage will be half that developed in the cathode circuit. If the impedance of the tuned circuit is equal to the cathode resistance at resonance, the audio voltage will be divided equally between the plate and cathode circuits. Since these voltages are 180 degrees out of phase—as in a kangaroo phase inverter—the audio voltage will be zero at the junction of R1 and R2.

R1 and R2 may be replaced by a potentiometer to permit balancing the system for best performance. The cathode capacitor is chosen to have a reactance much smaller than the cathode resistor at the lowest signal frequency—usually 550 kc—and much larger than the resistor at the resonant frequency of L-C2 (approximately 9,000 cycles). C1 is selected for a reactance equal to the resistance of R1 plus R2 at the lowest audio frequency to be passed by the audio system. If its reactance is too high, bass boost will be introduced. Feedback will occur at low frequencies if the reactance is too low. L is a 30-mh shielded r.f. choke. One with a powdered-iron core is preferable. C2 should be a high-quality mica unit. L-C2 may be replaced with a commercial heterodyne filter if it is considered desirable.

If the receiver has a separate detector, the filter may be incorporated in an a.f. amplifier stage. In such cases, the cathode bypass capacitor is omitted and the cathode resistor adjusted for normal amplifier operation.